A TECHNIQUE FOR PROCESS-QUALIFYING A SEMICONDUCTOR MANUFACTURING TOOL USING METROLOGY DATA

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CROSS REFERENCE TO RELATED APPLICATION

This application is related to and claims the priority of U.S. Provisional Application Serial No. 60/491,974, filed August 4, 2003, which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to semiconductor manufacture. More particularly, the present invention relates to techniques for qualifying semiconductor manufacturing tools. Even more specifically, one or more embodiments of the present invention relate to techniques for qualifying a CMP tool using metrology data measured from a single wafer.

BACKGROUND OF THE INVENTION

In the fabrication of integrated circuits, numerous integrated circuits are typically constructed simultaneously on a single semiconductor wafer. The wafer is then later subjected to

a singulation process in which individual integrated circuits are singulated (i.e., extracted) from the wafer.

At certain stages of this fabrication process, it is often necessary to polish a surface of the semiconductor wafer. In general, a semiconductor wafer can be polished to remove high topography, surface defects such as crystal lattice damage, scratches, roughness, or embedded particles of dirt or dust. This polishing process is often referred to as mechanical planarization (MP) and is utilized to improve the quality and reliability of semiconductor stations. In typical situations, these processes are usually performed during the formation of various devices and integrated circuits on the wafer.

The polishing process may also involve the introduction of a chemical slurry (e.g., an alkaline or acidic solution). This polishing process is often referred to as chemical mechanical planarization (CMP). Much like mechanical planarization processes, chemical mechanical polishing is widely used in semiconductor processing operations as a process for planarizing various process layers, e.g., silicon dioxide, which is formed upon a wafer comprised of a semiconducting material, such as silicon. Chemical mechanical polishing operations typically employ an abrasive or abrasive-free slurry distributed to assist in planarizing the surface of a process layer through a combination of mechanical and chemical actions (i.e., the slurry facilitates higher removal rates and selectivity between films of the semiconductor surface).

During the normal course of operation, any number of reasons may necessitate the qualification or re-qualification of these mechanical and chemical mechanical polishing tools. Generally speaking, qualification procedures constitute the process steps required to calibrate and otherwise prepare a tool for production or service (e.g., so that the devices produced by the

tool meet minimum predetermined specification requirements, as dictated by the demands of the individual fabs and/or product lines). For example, due to normal wear, a polishing pad may no longer be fit for service, and may need to be replaced by a new pad. In these instances, the qualification procedure collects a number of qualification characteristics (e.g., using the metrology data) measured during initial use of the new pad on sets of blanket or "test" wafers (i.e., wafers having only a thin film of unpatterned material). The qualification procedure then makes appropriate modifications to the tool recipe based on the measured qualification characteristics to ensure that future production runs comport with, for example, a number of minimum specification requirements. In a similar manner, a new tool (e.g., a tool beginning production of a new semiconductor product line) must also be qualified before it can be put into production.

Conventional methods for process-qualifying the above-described tools consume a large numbers of test wafers (approximately 10 to 15 test wafers) and require lengthy amounts of time. With regard to the large amount of time required, this is due to the nature of the stand-alone sensors and metrology devices (i.e., metrology devices that are separate from the tools) used to collect the required qualification characteristics. In particular, because the sensors are separate from the processing tools, in order to collect the qualification characteristics, a typical process first requires measuring preprocessing characteristics followed by physically moving a wafer into the processing tool, where the wafer is processed. After processing, the wafer is removed from the tool and returned to the metrology device, where post-processing characteristics are measured and used in conjunction with the preprocessing characteristics to obtain the characteristics used in qualifying the tool (i.e., the qualification characteristics).

With these conventional methods, the amount of time required to move the wafers back and forth between the tools and the metrology devices is significant. Furthermore, with tools having multiple components or chambers with each requiring qualification, it was more efficient to qualify the chambers in parallel, thus resulting in the consumption of additional wafers. To illustrate, the convention methods may use one wafer to qualify a first chamber or first tool component, a second wafer to qualify a second chamber or second tool component, and a third wafer to qualify a third chamber or third tool component.

In addition to the test wafers, conventional methods often require the testing of a "look-ahead" or patterned production wafer. The testing of these look ahead-wafers was used to ensure that the polishing process met specifications under actual production circumstances.

Recently, conventional in situ metrology devices have been able to eliminate the time required by stand-alone sensors to transfer wafers back and forth between the tools and the metrology devices. However, these conventional devices did not necessarily collect the qualification characteristics used to properly qualify a tool. For instance, conventional in situ metrology devices did not measure film thickness, which is used to qualify tools for, for example, nonuniformity and polishing rate. Consequently, conventional techniques were still required to qualify tools (such as polishing tools) requiring such measurements.

One of the disadvantages of conventional qualification procedures is the cost associated with the testing of these large amounts of blanket and test wafers. In addition to the cost of the test wafers, there is a significant time penalty associated with the qualification procedures. That is, the tools cannot be used to produce products during the qualification process. Furthermore,

the processing of test wafers subtracts from the useful life of the polishing pads, since they have only a finite amount of polishing cycles before requiring a change.

Accordingly, increasingly efficient techniques for qualifying such polishing processes are needed. Specifically, what is required is a technique that greatly reduces the number of wafers required for properly qualifying a polishing process. In this manner, the cost and time associated with obtaining a production-ready polishing process may be minimized.

SUMMARY OF THE INVENTION

The present invention addresses the needs and the problems described above by providing a technique for process qualifying a semiconductor manufacturing tool using qualification characteristics measured from a reduced number of wafers (e.g., in at least some embodiments, a single wafer). In at least some embodiments, the technique commences during the processing of a wafer with the manufacturing tool. During processing, the technique involves using an in situ metrology device able to measure from the wafer one or more qualification characteristics required to properly qualify the tool (e.g., wafer thickness information). Thus, wafers need not be transferred from the tool in order to collect qualification characteristics. Subsequently, the manufacturing tool is qualified by adjusting one or more parameters of a recipe in accordance with the qualification characteristics measured from the wafer to target one or more manufacturing tool specifications.

In one or more parallel and at least somewhat overlapping embodiments, the tool to be qualified includes a bulk removal polishing platen, a copper clearing platen and a barrier removal

polishing platen. In these cases, the technique involves transferring a wafer to each of the bulk removal polishing, copper clearing and barrier removal polishing platens, where qualification characteristics are measured during wafer processing. These platens are subsequently qualified by adjusting one or more parameters of a recipe associated with each platen in accordance with the qualification characteristics measured from the wafer, to target one or more platen specifications.

In one or more other parallel and at least somewhat overlapping embodiments, the technique involves measuring a defectivity from the wafer during processing. Subsequently, the technique qualifies the tool for detectivity by adjusting one or more parameters of the recipe in accordance with the defectivity measured during processing to target a defectivity specification.

BRIEF DESCRIPTION OF THE DRAWINGS

Various objects, features, and advantages of the present invention can be more fully appreciated as the same become better understood with reference to the following detailed description of the present invention when considered in connection with the accompanying drawings, in which:

FIG. 1 is a perspective view of at least one example of a chemical mechanical planarization (CMP) apparatus;

FIG. 2 depicts a block diagram of a metrology system that can be used in conjunction with the apparatus FIG. 1;

FIG. 3 illustrates at least one example of the operation of the apparatus of FIG. 1, during which the qualification or requalification process of at least some embodiments of the present invention may be utilized;

FIG. 4 illustrates at least one example of a polishing process for controlling the apparatus of FIG. 1;

FIG. 5 illustrates at least one example of a process utilizable for collecting the qualification characteristics required for use with the qualification process of the present invention;

FIGS. 6a and 6b illustrate at least one example of a process which utilizes the qualification characteristics from a single wafer to properly qualify a polishing tool;

FIG. 7 is a high-level block diagram depicting at least some of the aspects of computing devices contemplated as part of and for use with at least some embodiments of the present invention; and

FIG. 8 illustrates one example of a memory medium which may be used for storing a computer implemented process of at least some embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with at least some embodiments of the present invention, a technique is provided for process-qualifying a semiconductor manufacturing tool using the qualification characteristics from a reduced number of wafers (e.g., in at least some embodiments, a single

wafer). Specifically, during processing of a wafer by the tool, the present invention contemplates measuring one or more qualification characteristics from the wafer using an in situ sensor or metrology device necessary for properly qualifying the tool. Subsequently, the manufacturing tool is qualified by adjusting one or more parameters of a recipe in accordance with the qualification characteristics measured from the wafer to target one or more manufacturing tool specifications.

FIG. 1 depicts at least one example of a chemical mechanical planarization (CMP) apparatus 120 utilizable for implementing at least some of the aspects of the present invention. Apparatus 120 includes a lower machine base 122 with a tabletop 128 mounted thereon and a removable outer cover (not shown). The tabletop 128 supports a series of polishing stations, including a first polishing station 125a, a second polishing station 125b, a third polishing station 125c, and a transfer station 127. The transfer station 127 serves multiple functions, including, for example, receiving individual wafers or substrates 110 from a loading apparatus (not shown), washing the wafers, loading the wafers into carrier heads 180, receiving the wafers 110 from the carrier heads 180, washing the wafers 110 again, and transferring the wafers 110 back to the loading apparatus.

A computer based controller 190 is connected to the polishing system or apparatus 120 for instructing the system to perform one or more processing steps on the system, such as polishing or qualification process on apparatus 120. The invention may be implemented as a computer program-product for use with a computer system or computer based controller 190. Controller 190 may include a CPU 192, which may be one of any form of computer processors that can be used in an industrial setting for controlling various chambers and subprocessors. A memory 194 is coupled to the CPU 192 for storing information and instructions to be executed

by the CPU 192. Memory 194, may take the form of any computer-readable medium, such as, for example, any one or more of readily available memory such as random access memory (RAM), read only memory (ROM), floppy disk, hard disk, or any other form of digital storage, local or remote. In addition, support circuits 196 are coupled to the CPU 192 for supporting the processor in a conventional manner. As will be discussed in greater detail below in conjunction with FIG. 7, these circuits may include cache, power supplies, clock circuits, input/output circuitry and subsystems, and can include input devices used with controller 190, such as keyboards, trackballs, a mouse, and display devices, such as computer monitors, printers, and plotters.

A process, for example the qualification process described below, is generally stored in memory 194, typically as a software routine. The software routine may also be stored and/or executed by a second CPU (not shown) that is remotely located from the hardware being controlled by the CPU 192.

Each polishing station includes a rotatable platen 130 on which is placed a polishing pad 100a, 100b, and 100c. If wafer 110 is an eight-inch (200 millimeter) or twelve-inch (300 millimeter) diameter disk, then platen 130 and polishing pad 100 will be about twenty or thirty inches in diameter, respectively. Platen 130 may be connected to a platen drive motor (not shown) located inside machine base 122. For most polishing processes, the platen drive motor rotates platen 130 at thirty to two hundred revolutions per minute, although lower or higher rotational speeds may be used.

The polishing stations 125a-125c may include a pad conditioner apparatus 140. Each pad conditioner apparatus 140 has a rotatable arm 142 holding an independently rotating conditioner

head 144 and an associated washing basin 146. The pad conditioner apparatus 140 maintains the condition of the polishing pad so that it will effectively polish the wafers. Each polishing station may include a conditioning station if the CMP apparatus is used with other pad configurations.

A slurry 150 containing a reactive agent (e.g., deionized water for oxide polishing) and a chemically-reactive catalyzer (e.g., potassium hydroxide for oxide polishing) may be supplied to the surface of polishing pad 100 by a combined slurry/rinse arm 152. If polishing pad 100 is a standard pad, slurry 150 may also include abrasive particles (e.g., silicon dioxide for oxide polishing). Typically, sufficient slurry is provided to cover and wet the entire polishing pad 100. Slurry/rinse arm 152 includes several spray nozzles (not shown) which provide a high-pressure rinse of polishing pad 100 at the end of each polishing and conditioning cycle. Furthermore, several intermediate washing stations 155a, 155b, and 155c may be positioned between adjacent polishing stations 125a, 125b, and 125c to clean wafers as they pass from one station to another.

In at least one embodiment of the present invention, the first polishing station 125a has a first pad 100a disposed on platen 130 for removing bulk copper-containing material disposed on the wafer (i.e., a bulk removal polishing platen). The second polishing station 125b has a second pad 100b disposed on a platen 130 for polishing a wafer to remove residual copper-containing material disposed on the wafer (i.e., a copper clearing platen). A third polishing station 125c having a third polishing pad 100c may be used for a barrier removal polishing process following the two-step copper removal process (i.e., a barrier removal polishing platen).

A rotatable multi-head carousel 160 is positioned above the lower machine base 122. Carousel 160 includes four carrier head systems 170a, 170b, 170c, and 170d. Three of the carrier head systems receive or hold the wafers 110 by pressing them against the polishing pads

100a, 100b, and 100c, disposed on the polishing stations 125a-125c. One of the carrier head systems 170a-170d receives a wafer 110 from and delivers a wafer 110 to the transfer station 127. The carousel 160 is supported by a center post 162 and is rotated about a carousel axis 164 by a motor assembly (not shown) located within the machine base 122. The center post 162 also supports a carousel support plate 166 and a cover 188.

The four carrier head systems 170a-170d are mounted on the carousel support plate 166 at equal angular intervals about the carousel axis 164. The center post 162 allows the carousel motor to rotate the carousel support plate 166 and orbit the carrier head systems 170a-170d about the carousel axis 164. Each carrier head system 170a-170d includes one carrier head 180. A carrier drive shaft 178 connects a carrier head rotation motor 176 to the carrier head 180 so that the carrier head 180 can independently rotate about its own axis. There is one carrier drive shaft 178 and motor 176 for each head 180. In addition, each carrier head 180 independently oscillates laterally in a radial slot 172 formed in the carousel support plate 166.

The carrier head 180 performs several mechanical functions. Generally, the carrier head 180 holds the wafer 110 against the polishing pads 100a, 100b, and 100c, evenly distributes a downward pressure across the back surface of the wafer 110, transfers torque from the drive shaft 178 to the wafer 110, and ensures that the wafer 110 does not slip out from beneath the carrier head 80 during polishing operations.

A description of a similar apparatus may be found in U.S. Patent 6,159,079, the entire disclosure of which is incorporated herein by reference. A commercial embodiment of a CMP apparatus could be, for example, any of a number of processing stations or devices offered by Applied Materials, Inc. of Santa Clara, California including, for example, any number of the

Mirramesa™ and Reflexion™ line of CMP devices. Also, while the device depicted in FIG. 1 is implemented to perform polishing processes and includes any polishing stations, it is to be understood that the concepts of the present invention may be utilized in conjunction with various other types of semiconductor manufacturing processes and processing resources including for example non-CMP devices, etching tools, deposition tools, plating tools, etc. Other examples of processing resources include polishing stations, chambers, and/or plating cells, and the like.

FIG. 2 depicts a block diagram of a metrology system of a single polishing station (e.g., any one or combination of stations 125a - 125c) of FIG. 1 that may be used in conjunction with the qualification process of the present invention. More specifically, the metrology system includes an in situ sensor 210 and a control system 215. In situ sensor 210 may be utilized in real time to measure one or more qualification characteristics during execution of the polishing steps of a qualification process, as well as during the polishing steps of an actual production process. As a result, wafers are not required to be removed from the polishing station in order to collect metrology data. These qualification characteristics in turn may be used to qualify a polishing station (e.g., stations 125a - 125c) of the apparatus of FIG. 1.

In situ sensor 210 may include a wafer thickness measuring device for measuring a topography of the wafer face during polishing. By being able to measure thickness in real-time, in situ sensor 210 is capable of providing a number of qualification characteristics used to properly qualify a semiconductor manufacturing tool. Specific types of in Situ sensors include laser interferometer measuring devices, which employ interference of light waves for purposes of measurement. One example of such an in situ sensor suitable for use with the present invention includes the In Situ Removal Monitor (ISRM) offered by Applied Materials, Inc. of Santa Clara, California. Similarly, in situ sensor 210 may include devices for measuring capacitance changes

or eddy currents (such as the iScan monitor, also offered by Applied Materials, Inc. of Santa Clara, California), optical sensors (such as the Nanospec series of metrology devices offered by Nanometrics of Milpitas, California or Nova 2020 offered by Nova Measuring Instruments, Ltd. of Rehovot, Israel), devices for measuring frictional changes, and acoustic mechanisms for measuring wave propagation (as films and layers are removed during polishing), all of which may be used to detect thickness in real time. Furthermore, it should be noted that at least some embodiments of the present invention contemplate implementing an in situ sensor capable of measuring both oxide and copper layers. Other examples of wafer property measuring devices contemplated by at least some embodiments of the present invention include integrated CD (critical dimension) measurement tools, and tools capable of performing measurements for dishing, erosion and residues, and/or particle monitoring, etc.

Any combination of the above sensors may be utilized with the present invention. For instance, in the example of FIG. 1, a capacitance or eddy current measuring sensor may be utilized in conjunction with bulk removal polishing station 125a, a light wave measuring sensor may be utilized in conjunction with copper clearing station 125b, and an optical sensor may be utilized in conjunction with barrier removal polishing station 125c.

Referring back to FIG. 2, in accordance with at least some of the embodiments of the present invention, control system 215 implements a qualification process for controlling each of the steps required to attain a number of predetermined manufacturing specifications. Specifically, as will be discussed in greater detail below, during the qualification process of the present invention, control system 215 initially directs in situ sensor 210 to gather each of the qualification characteristics required to qualify apparatus 120 from a single wafer. Control system 215 subsequently modifies any number of recipe parameters in order to attain a number

of manufacturing specifications (determined according to fab or product demands) associated with apparatus 120. Thus, control system 215 is operatively coupled to, in addition to in situ sensor 210, components of apparatus 120 to monitor and control a number of qualification and manufacturing processes.

As mentioned above, in situ sensor 210 may be used to obtain various qualification characteristics, for example during qualification procedures, which may be compared against tool specifications to measure the efficiency of the process. Examples of such characteristics are the removal rate of the film material to be removed from the wafer, the uniformity or nonuniformity in the material removal, the defectivity, and other similar and analogous metrics. These and other characteristics are indicators of the quality of the polishing process. The removal rate is mainly used to determine the polishing time of product wafers. The nonuniformity directly affects the global planarity across the wafer surface, which becomes more important as larger wafers are used in the fabrication of devices. The defectivity indicates the number of defects occurring due to for example scratches in the wafer. Each of the above depends on and may be affected by the polishing parameters of the process recipe. Thus, parameters such as the applied pressure or downward force, the speed of the polishing table, the speed of the wafer carrier, the slurry composition, the slurry flow, and others, may be modified to adjust the characteristics, in an attempt to satisfy minimum tool specification levels.

FIG. 3 illustrates at least one example of operation of a polishing tool (e.g., tool 120 of FIG. 1), during which the tool may require qualification or requalification according to the concepts of the present invention. As discussed above, before a tool may be placed on-line and into production, it must be qualified to meet minimum specification levels. Thus, before production commences on the tool, it is first qualified (STEP 310). After qualification, the tool

may begin processing wafers (STEP 320). For example, processing may be directed according to a tool recipe downloaded onto the tool.

During the normal course of operation, the tool may require routine forms of maintenance. For example, the polishing pads and other components of the tool may need to be replaced due to normal wear. In some cases, the tool determines whether maintenance is necessary by identifying process results that are no longer within minimum specifications (e.g., process drifts). In other cases, the tools may be serviced periodically. In any case, once it is determined that maintenance is necessary (STEP 330), the required maintenance is performed (STEP 340). For example, the worn polishing pads or other parts may be replaced.

In other instances, a new tool recipe for controlling the tool may be implemented (STEP 350). For example, the tool may be directed to produce another product. Similarly, different wafers and substrates, with different characteristics, may be delivered for processing by the tool. Both of these cases (and others) require the implementation of a new recipe. Whatever the case, the new recipe is downloaded onto the tool (STEP 360).

In each of the above (and other) situations, the tool must be requalified before production can recommence (STEP 310). As discussed, the qualification procedure ensures that the results of processing by the tool meet a number of minimum specification levels. Once qualified, the tool recommences the processing of wafers (STEP 320).

As discussed, the qualification procedure of the present invention is utilizable with a multi-step polishing process for removing conductive materials and conductive material residues from a wafer or substrate surface using one or more polishing pads. One example of such a polishing processes is described with reference to FIG. 4. Initially, a wafer is transferred from an

upstream tool to the polishing tool (STEP 404). In the example of FIG. 1, the wafer may be transferred from an electrochemical plating (ECP) tool to bulk removal polishing platen 125a of tool 120. Subsequently, a tool recipe for controlling the polishing tool is downloaded and implemented on the tool (STEP 408).

At the bulk removal polishing platen, a first polishing composition is used with a first polishing pad to remove bulk copper containing material from the wafer surface to substantially planarize the bulk copper containing material (STEP 412). Bulk removal polishing continues until a predetermined amount of copper is removed from the wafer as determined by, for example, an eddy current or capacitance endpoint sensor (or any other analogous or suitable sensor) (STEP 416). In addition, feedback data may be collected by the sensor for use in optimizing future runs (STEP 414). From there, the wafer is delivered to a second or copper clearing polishing platen (e.g., platen 125b).

At the copper clearing platen, a second polishing composition is used with a second polishing pad to remove remaining residual copper containing material (STEP 420). The residual copper containing material removal process terminates when the underlying barrier layer has been reached (STEP 424). This can be determined by, for example, an optical or light-sensing metrology device. In addition, the metrology device may be used to collect feedback data for use in optimizing future runs (STEP 422). Subsequently, the wafer is transported to a third or barrier removal polishing platen (e.g., platen 125c).

At the barrier removal polishing platen, a third polishing composition is used with a third polishing pad to remove the barrier layer (STEP 428). This layer is typically formed on the wafer surface above a dielectric layer. Polishing continues until, for example, the barrier layer,

and in some cases a portion of the underlying dielectric, has been removed (STEP 432). This can be determined by, for example, an optical sensor and the like. Afterwards, the wafer may be transferred to a cleaning module or subjected to an in situ cleaning process to remove surface defects, or to some other downstream tool for further processing (STEP 436).

As discussed above, maintenance (e.g., pad replacement at any or all of the above-described platens) requires the requalification of the polishing tool. In accordance with at least some of the concepts of the present invention, and as will be discussed in greater detail below, the in situ metrology devices (i.e., in situ sensors) described above for collecting endpoint and feedback data may be utilized to collect substantially all of the qualification characteristics, during a qualification procedure, required to properly qualify any or all of the platens of the polishing tool, from a single wafer. Specifically, at least some of the embodiments of the present invention contemplate using a single patterned or production wafer as the source of substantially all of the metrology wafer data required to properly qualify a tool. In other embodiments, other wafers, such as a single blanket wafer may be used. This is the case because use of the in situ metrology devices or sensors allows measuring of the qualification techniques without removal of the wafer from the tool. As a result, the present invention greatly reduces the time and costs associated with qualifying a polishing tool.

Referring now to FIG. 5, at least one example of a process utilizable for collecting the necessary qualification characteristics is described. As discussed, the qualification characteristics collected from the processing of a single wafer is sufficient to properly qualify the polishing tool. Initially, after receiving the wafer at tool 120, the wafer is premeasured for defects (STEP 504). Specifically, the number of defects existing on the wafer may be measured

using an optical metrology device or the like. For example, the Compass laser-sensing device offered by Applied Materials may be utilized.

Subsequently, the wafer is positioned on bulk removal polishing platen 125a (STEP 508). Bulk copper containing materials are then removed by polishing the surface of the wafer (STEP 512). In conjunction with the bulk removal polishing procedure, a sensor or other metrology device (e.g., in situ sensor 210) collects metrology data from the wafer (STEP 516). In particular, the sensor may be implemented to collect, for example, the thickness of the bulk copper material before and after polishing, as well as a polishing time and the level of current in the material during processing. In addition, the data measured by the metrology device also dictates when to terminate the bulk removal polishing process. For example, in the case of an eddy current sensor, which is capable of using current changes to detect changes in film characteristics (e.g., changes in film characteristics, such as thickness, directly affect a current), processing terminates when the measured current drops below or rises above a predetermined level. As will be discussed in greater detail below, this metrology data is collected and analyzed for purposes of qualifying bulk removal polishing platen 125a of polishing tool 120.

After the bulk removal polishing process has been completed, the wafer is positioned on copper clearing platen 125b (STEP 520). At the copper clearing platen, residual copper containing materials are removed by polishing the surface of the wafer (STEP 520). In conjunction with the copper clearing procedure, a sensor such as the ISRM collects metrology data from the wafer (STEP 528). In particular, the sensor may be implemented to collect, for example, the polishing time required to clear the copper from the wafer and the level of light intensity in the material during polishing. As with the bulk removal polishing platen, the data measured by this metrology device also dictates when to terminate the copper clearing process.

For example, in the case of an optical sensor, which is capable of detecting changes in light intensity (e.g., a change from copper film to a barrier material directly affects light intensity), processing terminates when the intensity of the measured light drops below or rises above a predetermined level. As will be discussed in greater detail below, this metrology data is collected and analyzed for purposes of qualifying copper clearing platen 125b of polishing tool 120.

After the copper clearing process has been completed, the wafer is positioned on a barrier removal polishing platen (STEP 532). At the barrier removal polishing platen, barrier layer materials are removed by polishing the surface of the wafer (STEP 536). In conjunction with this procedure, a sensor, such as an optical sensor or the like, collects metrology data from the wafer (STEP 540). In particular, the sensor may be implemented to collect, for example, the polishing time required to clear the copper from the wafer and the level of light intensity in the material during polishing. As with the previous platens, the data measured by this metrology device also dictates when to terminate the barrier removal polishing process. For example, in the case of an optical sensor, which is capable of detecting a change in light intensity (e.g., a change from barrier material to a dielectric material directly affects light intensity), processing terminates when the intensity of the measured light drops below or rises above a predetermined level. As will be discussed in greater detail below, this metrology data is collected and analyzed for purposes of qualifying barrier removal polishing platen 125c of polishing tool 120.

After wafer polishing has been completed, the wafer is delivered to a wafer defectivity sensor, where the wafer is measured for defects (STEP 544). For example, the wafer may be measured for its total number of detects using the metrology device utilized in STEP 504, as described above.

In accordance with at least some of the concepts of the present invention, the metrology data gathered from a single wafer during the process described in FIG. 5 (STEPS 504, 516, 528, 540, and 544) constitutes substantially all of the qualification characteristics required to properly qualify a polishing tool. One example of a process that utilizes this data to properly qualify a polishing tool is depicted in FIGS. 6a and 6b.

Referring to FIGS. 6a and 6b, processing commences with the calculation of each of the qualification characteristics required to properly qualify bulk removal polishing platen 125a. In at least some embodiments, the raw metrology data measured during processing of the test wafer at the bulk removal polishing platen constitutes the required qualification data. In other cases, a step of processing must be performed to convert the raw metrology data into usable form. For example, thickness data at several points may need to be averaged before use. In at least some embodiments of the present invention, the qualification characteristics may include a polishing rate and a nonuniformity (although other qualification characteristics are possible). In these cases, the process calculates the polishing rate and nonuniformity of the platen (STEP 604) using the metrology data measured during processing of the test wafer at bulk removal polishing platen 125a (e.g., STEP 516). Specifically, the process utilizes the starting thickness of a bulk material, the ending thickness of the material, and the time required to reach the ending thickness to obtain the polishing rate of the platen. Similarly, the measured metrology data (i.e., the film thickness at a number of predetermined points across the wafer) may be utilized to generate a wafer profile. This profile, in turn may be used to obtain the nonuniformity of the wafer resulting from the bulk removal polishing process.

From there, the process compares the qualification characteristics against the minimum tool specifications. Thus, the process first compares the polishing rate against a polishing rate

specification for bulk removal polishing platen 125a (STEP 608). If the polishing rate is not within specification, appropriate adjustments are made to the tool recipe so that future runs (i.e., actual production runs) are within specification limits (STEP 612). For example if the polishing rate exceeds the specification rate, the bulk removal polishing platen pressure may be reduced. After qualifying bulk removal polishing platen 125a for its polishing rate, the process next compares the nonuniformity against a specification nonuniformity for the bulk removal polishing platen (STEP 616). If the nonuniformity is not within specification, appropriate adjustments are made to the tool recipe so that future runs (i.e., actual production runs) are within specification limits (STEP 620). For example, the polishing pressures applied by various zones in a polishing head to the wafer may be adjusted. Similarly, the slurry composition used in the bulk removal polishing process may be adjusted. As known by those of ordinary skill in the art, the exact adjustments made by the process to comport with tool specifications may be determined in view of, for example, design of experiments (DOE) information and other similar data. After qualifying bulk removal polishing platen 125a for nonuniformity, qualification shifts to copper clearing platen 125b.

Processing continues with the calculation of each of the qualification characteristics necessary to properly qualify copper clearing platen 125b. As with the bulk removal polishing qualification procedure, the qualification characteristics may take the form of either raw or processed data. In at least some embodiments of the present invention, the qualification characteristics may include a polishing rate and a nonuniformity (although other qualification characteristics are possible). In these cases, the process uses the metrology data measured during processing of the test wafer at copper clearing platen 125b (e.g., STEP 528) to calculate the polishing rate and nonuniformity of the platen (STEP 624). Specifically, the process utilizes the

starting thickness of the copper residue material (as measured, e.g., at the end of the bulk removal qualification process) and the time required to clear the remaining material to determine polishing rate of the platen. The change in light intensity taken as a function of time (measured by the copper clearing platen metrology device) may be utilized to determine the nonuniformity of the wafer resulting from processing by copper clearing platen 125b.

Subsequently, the process compares the qualification characteristics against minimum tool specifications. Thus, the process compares the polishing rate against a polishing rate specification for the copper clearing platen 125b (STEP 628) and the nonuniformity against the nonuniformity specification for the copper clearing platen 125b (STEP 636). If either of these qualification characteristics is not within specification, appropriate adjustments may be made to the tool recipe so that future runs (i.e., actual production runs) are within specification limits (STEP 632 and STEP 640). After qualifying copper clearing platen 125b, qualification shifts to barrier removal polishing platen 125c.

Processing continues with the calculation of each of the qualification characteristics necessary to properly qualify barrier removal polishing platen 125c. As with the above, the qualification characteristics may take the form of either raw or processed data. In at least some embodiments of the present invention, the qualification characteristics may include a polishing rate and a nonuniformity (although other qualification characteristics are possible). In these cases, the process uses the metrology data measured during processing of the test wafer at barrier removal polishing platen 125c (e.g., STEP 540) to calculate the polishing rate and nonuniformity of the platen (STEP 644). Specifically, the process utilizes the starting thickness of the barrier material (as measured, e.g., at the end of the copper clearing qualification process), the remaining thickness of a dielectric layer (i.e., the layer underlying the barrier layer), and the total

polishing time to determine the polishing rate of the platen. Similarly, the process measures the thickness of the wafer at a predetermined number of points (e.g., 15-20 points) to determine the nonuniformity of the wafer resulting from barrier removal polishing platen 125c.

Subsequently, the process compares the qualification characteristics against minimum tool specifications. Thus, the process compares the polishing rate against a polishing rate specification for barrier removal polishing platen 125c (STEP 648) and the nonuniformity against the nonuniformity specification for barrier removal polishing platen 125c (STEP 656). If either of these qualification characteristics is not within specification, appropriate adjustments may be made to the tool recipe so that future runs (i.e., actual production runs) are within specification limits (STEP 652 and STEP 660). After qualifying barrier removal polishing platen 125c, qualification shifts to defectivity.

To qualify the polishing tool for defectivity, the process compares the number of defects measured before the polishing (e.g., STEP 504) against the number of defects after polishing (e.g., STEP 544) (STEP 664), and determines whether the change in the number of defects is within specification (STEP 668). If the change in the number of defects is within specification, processing ends. However, if the change in the number of defects is not within specification, appropriate adjustments may be made to the tool recipe so that future runs (i.e., actual production runs) are within specification limits (STEP 672). For example, the chemical composition of the slurry used in one of the polishing processes may be adjusted. In other embodiments, to qualify the polishing tool for defectivity, instead of analyzing the change in the number of defects, the number of defects measured after polishing (e.g., STEP 544) is compared against a specification limit or other requirement.

As discussed above, the qualification process of the present invention may be implemented in any computer system or computer-based controller. One example of such a system is described in greater detail below with reference to FIG. 7. Specifically, FIG. 7 illustrates a block diagram of one example of the internal hardware of control system 215 of FIG. 2, examples of which include any of a number of different types of computers such as those having Pentium™ based processors as manufactured by Intel Corporation of Santa Clara, California. A bus 756 serves as the main information link interconnecting the other components of system 215. CPU 758 is the central processing unit of the system, performing calculations and logic operations required to execute the processes of the instant invention as well as other programs. Read only memory (ROM) 760 and random access memory (RAM) 762 constitute the main memory of the system. Disk controller 764 interfaces one or more disk drives to the system bus 756. These disk drives are, for example, floppy disk drives 770, or CD ROM or DVD (digital video disks) drives 766, or internal or external hard drives 768. CPU 758 can be any number of different types of processors, including those manufactured by Intel Corporation or Motorola of Schaumberg, Illinois. The memory/storage devices can be any number of different types of memory devices such as DRAM and SRAM as well as various types of storage devices, including magnetic and optical media. Furthermore, the memory/storage devices can also take the form of a transmission.

A display interface 772 interfaces display 748 and permits information from the bus 756 to be displayed on display 748. Display 748 is also an optional accessory. Communications with external devices such as the other components of the system described above, occur utilizing, for example, communication port 774. For example, port 774 may be interfaced with a bus/network linked to CMP device 20. Optical fibers and/or electrical cables and/or conductors

and/or optical communication (e.g., infrared, and the like) and/or wireless communication (e.g., radio frequency (RF), and the like) can be used as the transport medium between the external devices and communication port 774. Peripheral interface 754 interfaces the keyboard 750 and mouse 752, permitting input data to be transmitted to bus 756. In addition to these components, the control system also optionally includes an infrared transmitter 778 and/or infrared receiver 776. Infrared transmitters are optionally utilized when the computer system is used in conjunction with one or more of the processing components/stations that transmits/receives data via infrared signal transmission. Instead of utilizing an infrared transmitter or infrared receiver, the control system may also optionally use a low power radio transmitter 780 and/or a low power radio receiver 782. The low power radio transmitter transmits the signal for reception by components of the production process, and receives signals from the components via the low power radio receiver.

FIG. 8 is an illustration of an exemplary computer readable memory medium 884 utilizable for storing computer readable code or instructions including the model(s), recipe(s), etc). As one example, medium 884 may be used with disk drives illustrated in FIG. 7. Typically, memory media such as floppy disks, or a CD ROM, or a digital video disk will contain, for example, a multi-byte locale for a single byte language and the program information for controlling the above system to enable the computer to perform the functions described herein. Alternatively, ROM 760 and/or RAM 762 can also be used to store the program information that is used to instruct the central processing unit 758 to perform the operations associated with the instant processes. Other examples of suitable computer readable media for storing information include magnetic, electronic, or optical (including holographic) storage,

some combination thereof, etc. In addition, at least some embodiments of the present invention contemplate that the computer readable medium can be a transmission.

Embodiments of the present invention contemplate that various portions of software for implementing the various aspects of the present invention as previously described can reside in the memory/storage devices.

In general, it should be emphasized that the various components of embodiments of the present invention can be implemented in hardware, software, or a combination thereof. In such embodiments, the various components and steps would be implemented in hardware and/or software to perform the functions of the present invention. Any presently available or future developed computer software language and/or hardware components can be employed in such embodiments of the present invention. For example, at least some of the functionality mentioned above could be implemented using C or C++ programming languages.

It is also to be appreciated and understood that the specific embodiments of the invention described hereinbefore are merely illustrative of the general principles of the invention. Various modifications may be made by those skilled in the art consistent with the principles set forth hereinbefore.